MADE

MULTI ASSET DEMAND EXECUTION

CONSOLIDATED INTERIM REPORT

passivSYSTEMS

WESTERN POWER
DISTRIBUTION
Serving the Midlands, South West and Wales

CONTENTS

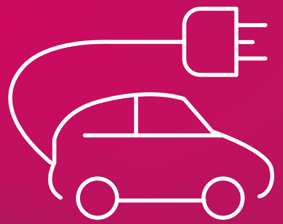
Abbreviation	Term
ADMD	After diversity maximum demand
BEIS	Department for Business, Energy and Industrial Strategy
BEV	Battery electric vehicle
BRISTOL	Buildings, renewables and integrated storage, with tariffs to overcome network limitations
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CMZ	Constraint management zone
DR	Demand response
DSR	Demand side response
DNO	Distribution network operator
DSO	Distribution system operator
ESS	Energy storage system
EHV	Extra high voltage
EV	Electric vehicle
FFR	Firm frequency response
FREEDOM	Flexible Residential Energy Efficiency Demand Optimisation and Management
GB	Great Britain
HHP	Hybrid heat pump
HHS	Hybrid heating system
HV	High voltage
HVAC	Heating, ventilation and air conditioning
LCT	Low carbon technologies
LRE	Load related expenditure
LV	Low voltage
MADE	Multi Asset Demand Execution
NIA	Network Innovation Allowance
OCGT	Open cycle gas turbine
Ofgem	Office of Gas and Electricity Markets
PAT	Public Attitudes Tracker
PV	Photovoltaics
SOC	State of charge
ToU	Time of use
TSO	Transmission system operator
V2G	Vehicle to grid
WeSIM	Whole-electricity System Investment Model
WPD	Western Power Distribution

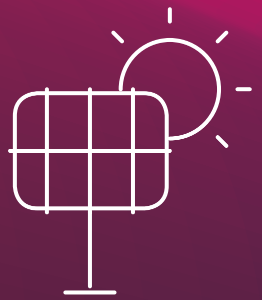
1 EXECUTIVE SUMMARY

The UK has made great strides in decarbonising the power sector and new, low carbon technologies (LCTs) are starting to reduce carbon emissions in the domestic heat and transport sectors. The decarbonisation of heat and transport is now a priority for the UK Government, following their commitment to bring all greenhouse gas emissions to net zero by 2050.

Solving the heating and transport challenge is complex. Solutions need to reduce carbon emissions while providing comfort, security and value to consumers, avoiding high capital costs by meeting consumer requirements without creating capacity peaks on the electricity system that would require large additional investments in network and generation capacity.

MADE is a world-first project that investigates the network, consumer and broader energy system implications of high volume deployments of the combination of domestic vehicle to home (V2H) electric vehicle (EV) charging, hybrid (domestic gas boiler and air-source heat pump) or heat pump heating systems, solar PV (photovoltaic) generation and storage.





Based on the lessons learned from previous Western Power Distribution (WPD) trials (FREEDOM, Electric Nation and SoLa Bristol), the project consortium has carried out microeconomic and system-level analysis, extrapolating previous trial findings in order to:

- Build a microeconomic model for domestic multi-asset, multi-vector flexibility for GB today.

  This will:
  - Identify the most attractive customer types;
  - Identify the high potential service stacks;
  - Quantify the value (£);
  - Include a particular focus on distribution system operator (DSO) services.
- Understand how the combined operation of residential solar PV generation, heat pump systems and smart EV charging may provide benefits to the consumer.
- Assess the whole-energy system benefits (including network infrastructure) and carbon benefits of large-scale deployment of the MADE concept.
- Consider conflicts and synergies between local community and national level objectives in the context of the flexibility enabled by the MADE concept.
- Estimate consumer benefits of the MADE concept, and inform the design of the market framework that would enable consumers to access the revenues that reflect the benefits delivered.

A FIVE-HOME TECHNOLOGY TRIAL WILL BE COMPLETED OVER THE 2019/2020 HEATING SEASON AND WILL BE USED TO VALIDATE THE MODELLED LEARNING.

To date, the project has successfully demonstrated that in-home multi-asset LCT control:

- Can provide distribution network benefits of distributed flexibility which can reach up to around £700m per year in annualised reinforcement cost when compared to the significant additional spend needed to accommodate non flexible LCTs. These are spread across low voltage (LV), high voltage (HV) and extra high voltage (EHV).

  Reinforcement cost savings diminish when looking further into the future to around £300-450m by 2035, which results from a very high penetration of EVs and hybrid heat pumps (HHPs) assumed in that time horizon, so that energy requirements become more prominent than power requirements.
- Is a notable value opportunity – up to £260 p.a. per household may be possible under best conditions.
- Offers material peak load shifting potential for the DSO – between 35-40% reductions in peak loads on the network compared to the baseline case (based on half-hourly data).

2 INTRODUCTION

2.1 PROJECT OVERVIEW

With increasing focus on the decarbonisation of heat and transport, LCT asset uptake is expected to rise dramatically.

Wide-scale adoption of EVs, low carbon heating and LV network-connected solar PV and storage will have a major impact on distribution network loads, requiring increased reinforcement while also increasing the necessity of a secure electricity supply. Past projects have explored each of these LCTs in isolation; none have explored their combined impact. Smart predictive control systems for LCT assets are emerging that could contribute significantly to the efficient operation of networks and the energy system, but could also create unexpected consequences from following energy price signals or optimising consumer demand if not properly aggregated and integrated into the energy system.

The Multi Asset Demand Execution (MADE) project aims to gain insight into the implications of utilising multiple energy assets within a home, and to better understand the feasibility of managing and aggregating these energy assets affordably to reduce network demand, minimising the requirement for network reinforcement. The project also aims to incentivise LCT uptake by unlocking network and broader energy system value from demand flexibility.

The energy assets considered under this project are:

- Hybrid heating systems (HHS) consisting of an electrically-powered heat pump (either air source or ground source) together with a fossil-fuel boiler (oil or gas), which together provide the heating and hot water requirements of the home;
- Solar PV panels;
- Domestic batteries;
- EV chargers with bi-directional capability.

The project consists of modelling work to evaluate the feasibility and benefits of multi-asset co-ordination at a household, feeder and whole-system level, alongside customer engagement work. The project also involves a small field test of the technologies to trial the proposed demand flexibility services.

This document is an interim report partway through the project, focusing on the output of modelling work and looking ahead to the pilot field trials in winter 2019-2020. It provides a summary of the work on the project to date (as well as previous related projects), bringing together results from each of the project partners, to make some overall conclusions.

2.2 PROJECT PARTNERS

Using existing relationships from the FREEDOM project, WPD has formed a project team that consists of PassivSystems, Everoze, Delta-EE, and Imperial College to deliver MADE. The project partners are all experts in their fields and will be managed by PassivSystems.

Figure 2.1 outlines the main roles performed by each of the project partners under the MADE project.

WPD
- Distribution network requirements.

PassivSystems
- Project management;
- Home energy management system;
- MADE control strategies;
- Field trial design.

Everoze
- Micro-economic energy modelling at domestic level;
- Inclusion of DSO services.

Delta-EE
- Customer research;
- Local network modelling;
- Business model development.

Imperial College
- Data analysis;
- Whole-system assessment on future GB electricity systems.

Figure 2.1 – MADE project partners overview

3 DATASETS FROM PREVIOUS PROJECTS

PassivSystems have carried out analysis of the data from three previous major projects:

- **The Electric Nation project**[1] which looked at smart charging of EVs;
- **The SoLa Bristol project**[2] which looked at integrating battery storage with PV panels;
- **The FREEDOM project**[3] which looked at HHPs.

These projects investigated the individual LCT assets in isolation that MADE is combining together, so the starting point of the MADE modelling exercise was to understand the conclusions from each of these projects and analyse their datasets to get insight into the MADE scenarios.

3.1 ELECTRIC NATION

PassivSystems have carried out extensive analysis of the Electric Nation dataset to understand patterns of EV usage and feed into the overall project designs.

In the next sections we provide the conclusions from this analysis and also summarise the project's own conclusions.

3.1.1 PASSIVSYSTEMS ANALYSIS CONCLUSIONS

The following observations can be drawn from PassivSystems' analysis on the Electric Nation dataset:

- EVs were typically connected for either between thirty minutes to four hours, or between nine and sixteen hours in a single charging transaction;
- The estimated charging duration per transaction was typically less than three hours;
- EVs were most commonly plugged in to the charger in the evening, between 17:00 and 19:30;
- There was a large amount of variation in battery state of charge (SOC) increase per charging transaction, particularly for battery electric vehicles (BEVs). BEVs typically underwent a SOC increase of less than 60%;
- The most common EV battery configuration found in the dataset was a 33kWh battery able to charge at 7kW.

3.1.2 ADDITIONAL ELECTRIC NATION PROJECT CONCLUSIONS

The following conclusions have also been evidenced by the Electric Nation project team:

- Trial data shows that there is scope for flexibility, particularly during the evening peak which aligns well with highest network demand;
- Demand management is technically feasible, and is acceptable to the majority of trial participants;
- Trial data shows that time of use (ToU) incentives appear to be highly effective at moving demand away from the evening peak;
- Without management, ToU incentives could lead to large peaks when electricity becomes cheap;
- Smart charging can:
  - Support the introduction and management of ToU-based charging;
  - Provide a means to manage any negative consequences of mass uptake of ToU incentive.

3.1.3 OVERALL CONCLUSIONS

PassivSystems' analysis of the Electric Nation dataset, coupled with the Electric Nation project conclusions, show there is clear scope for demand management, particularly during the evening peak. The trial also demonstrated that ToU incentives were effective in moving demand management from the evening peak, however trial data suggests that coordinated control between households may be required to manage the consequences of mass uptake of ToU incentives and prevent the introduction of new charging peaks. Overall, these conclusions provide strong support for MADE control. The Electric Nation data also provides a good foundation for the generation of a typical EV charging profile to feed into the MADE modelling work.

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[1] www.electricnation.org.uk/

[2] www.westernpower.co.uk/projects/sola-bristol

[3] www.westernpower.co.uk/projects/freedom

3.2 SOLA BRISTOL

PassivSystems have conducted analysis of the SoLa Bristol (Buildings, renewables and integrated storage, with tariffs to overcome network limitations) dataset to identify whether it is suitable for use in the MADE modelling to represent typical battery and solar PV operation.

Due to DNO control over the battery during the project, the SoLa Bristol data is not a typical representation of domestic battery use, and is therefore not appropriate to use to directly represent a typical household battery profile for use in MADE. Additionally, gaps in solar data, alongside a lack of orientation data regarding the installations, mean that the solar data is not ideal for use in forming typical PV generation data for use in the MADE modelling. Solar generation profiles for the MADE modelling have therefore been determined through analysis of relevant homes from PassivSystems' solar monitoring portfolio, and we have made assumptions about the operation of the domestic batteries from discussions with their manufacturers.

SOLAR GENERATION PROFILES FOR THE MADE MODELLING HAVE BEEN DETERMINED THROUGH ANALYSIS OF RELEVANT HOMES FROM PASSIVSYSTEMS' SOLAR MONITORING PORTFOLIO.

3.3 FREEDOM

FREEDOM (Flexible Residential Energy Efficiency Demand Optimisation and Management) was a Network Innovation Allowance (NIA) funded cross-sector collaboration between electricity and gas distribution networks WPD and Wales & West Utilities, who engaged PassivSystems to deliver the project, supported by partners Imperial College, Delta-EE and City University. The aim of the project was to investigate the network, consumer and broader energy system implications of high volume deployments of HHS.

Following the FREEDOM project, PassivSystems have developed an annual forecasting tool, enabling the gas and electricity demands of a HHS to be modelled, in order to provide heat pump demand profiles for use in the MADE modelling. The tool utilises PassivSystems' in-depth knowledge of heat pump operation, developed through the FREEDOM project, in conjunction with weather data, user defined schedules/setpoints, learnt thermal properties of the house and tariff information to look ahead in time and predict how the heat pump and boiler will behave in tandem to deliver householder comfort while minimising the cost. Energy predictions for each half-hourly period within a given year are then returned.

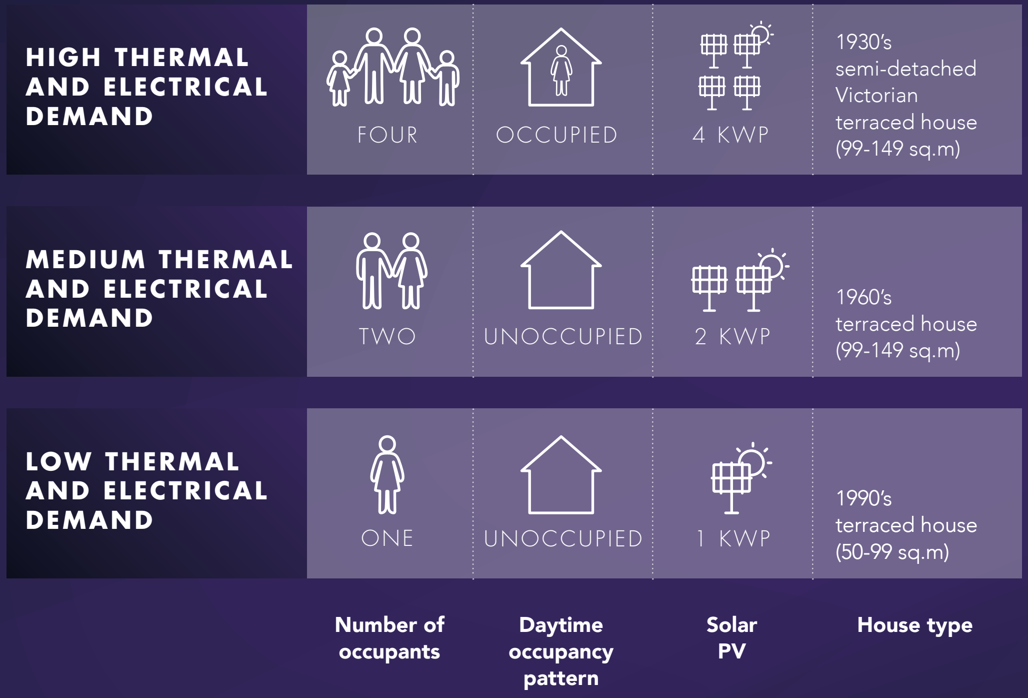
Using this annual forecasting tool, a selection of optimised 2018 heating profiles were generated, based on appropriate FREEDOM homes for use in the MADE modelling. These profiles were also provided to Everoze for use in their modelling.

Through the FREEDOM project, PassivSystems' have also gained knowledge on consumer acceptance of HHS operation, and therefore what demand management interventions may be acceptable to consumers. This will help to shape the MADE control strategy.

4 DOMESTIC LEVEL TECHNO-ECONOMIC MODELLING[4]

4.1 APPROACH

Following discussions between project partners, Delta-EE outlined three base customer types, defined by the type of property and household make-up, to be considered in the modelling, as shown in Figure 4.1.



	Number of occupants	Daytime occupancy pattern	Solar PV	House type
HIGH THERMAL AND ELECTRICAL DEMAND	FOUR	OCCUPIED	4 KWP	1930's semi-detached Victorian terraced house (99-149 sq.m)
MEDIUM THERMAL AND ELECTRICAL DEMAND	TWO	UNOCCUPIED	2 KWP	1960's terraced house (99-149 sq.m)
LOW THERMAL AND ELECTRICAL DEMAND	ONE	UNOCCUPIED	1 KWP	1990's terraced house (50-99 sq.m)

Figure 4.1 – Customer types used in the MADE modelling

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[4] The information and graphics in this section are taken from the following report: MADE: Modelling Results, Everoze, October 2019, Doc No: PASSIV001-S-02

Three EV use cases and transport patterns with different intensity of EV use have been considered:

- Commuter use case with heavy EV usage:

  Weekday commute to work, and weekend visits to friends and family

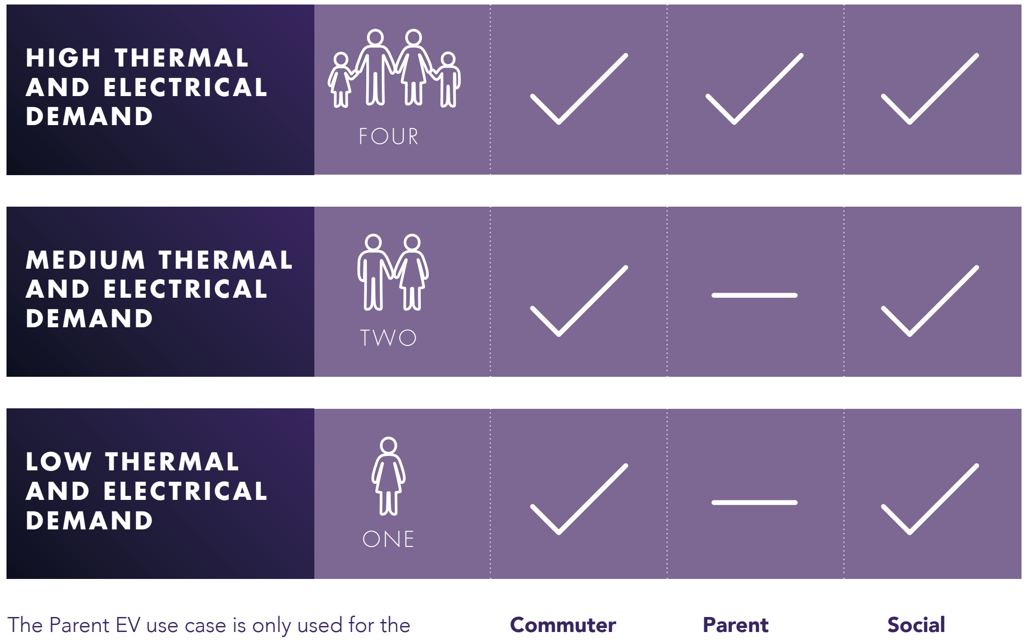
- Parent use case with moderate EV usage:

  Parent with school runs in the morning with high-intensity social use multiple times during the day

- Social use case with occasional low-intensity EV use:

  Three to four times a week (one to two evenings).

The base customer types and the EV transport patterns were used to inform the seven modelling cases considered by Everoze, which can be seen in Figure 4.2. These modelling cases provide a reasonable set of representative cases for Delta-EE to undertake its feeder-level modelling.



		Commuter	Parent	Social
HIGH THERMAL AND ELECTRICAL DEMAND	FOUR	✓	✓	✓
MEDIUM THERMAL AND ELECTRICAL DEMAND	TWO	✓	—	✓
LOW THERMAL AND ELECTRICAL DEMAND	ONE	✓	—	✓

The Parent EV use case is only used for the High demand customer type as that is the only customer type with children.

Figure 4.2 – Seven modelling cases used in the domestic level techno-economic MADE modelling

Two different modelling scenarios were considered for each customer type-EV use case combination:

1

Baseline Case

This includes a selection of LCTassets with no coordinated multi-asset co-ordinated delivery of flexibility (FLEX) provision;

2

Optimised Case

With the LCT assets operating in a coordinated manner (at a residential level) for FLEX provision.

Figure 4.3 details the assumptions made for each of the modelled energy assets in both the baseline and optimised cases.

BASELINE CASE	Included, installed kWp based on customer type	Included, ASHP loads optimised against price signals	Included, load-shifting using surplus solar	Included, unidirectional charger with smart charging
OPTIMISED CASE	Included, installed kWp based on customer type	Included, ASHP loads optimised against price signals	Included, load-shifting surplus solar and pre-charging as well as ancillary service provision	Included, bidirectional charger with smart charging as well as V2H/V2G service provision

Figure 4.3 – Asset operation assumptions in the baseline and optimised cases

The following revenue opportunities were utilised in the modelling:

- Peak shifting:

  Surplus solar generation during the day is used to charge the energy storage system (ESS) and EV (when available), which is then discharged during the evening peak demand period to reduce peak charges and reduce the impact of peak-time loads on the network. If surplus solar generation is not sufficient to meet the evening peak demand volume,
  the ESS and EV pre-charge when the energy price is low (e.g. night time) to top up the balance volume for peak shifting.

  Value accrued from peak shifting is the spread between the peak-time charge (sell action) and the cost of energy for charging the ESS/EV net of energy losses (buy action). A target spread of 10p/kWh is assumed in the modelling – peak shifting is only performed for that day if the buy-sell spread is more than 10p/kWh. If additional surplus solar over that needed for peak-time loads is available during the day, this is used by the ESS to shift loads during the off-peak hours. The aforementioned economic decision driver is not applied in this instance.

- Firm frequency response (FFR):

  Night-time FFR for FFR availability windows 1 and 2 (11pm-7am) is assumed as part of the revenue stack. Weekly FFR auctions are considered in the modelling in line with the ongoing FFR auction trials; a success rate of 75% is assumed. An FFR tariff of £5/MWh is assumed – this is based on the clearing prices in the recent weekly FFR auctions. A 3kW service volume is assumed. As noted previously, route-to-market is expected to be through aggregation to meet the minimum volume requirements.

- DSO services:

  DSO services are procured by WPD to manage constraints caused by a variety of reasons across its network (ie. overloads under peak demand conditions, overloads during summer outage season). The seasonal, day-of-week and time-of-day need for demand response (DR) required by WPD varies across its constraint management zones (CMZs) depending on the needs of the local network, which also informs the type of service procured by the DSO.

WPD currently procures two products across its CMZs:

Secure

Week-ahead notification of a scheduled demand turn-down or generation turn-up

Dynamic

Week-ahead notification of availability to provide demand turn-down or generation turn-up,with a close to real-time notification to provide response

Given the local nature of DSO service requirements, it is not possible to make a generalised assumption on the service profile for use in the revenue stack. To accommodate the variability in network constraint and service need across WPD's South Wales DSO region, a few scenarios with different DSO service stacks have been considered in the modelling.

One of these scenarios is considered for the base modelling for the seven modelling cases, with the assumption that the property is located in a part of the network where the system need is represented by this scenario. The remaining scenarios are considered in the sensitivity analyses.

4.2 RESULTS AND CONCLUSIONS

The estimated FLEX value (£/household/year) accrued is shown in Figure 4.4. Modelled benefits or 'value' from providing FLEX are calculated as the savings in electricity costs and revenues from ancillary services, less any cost of additional electricity imports. This does exclude asset capital or operating costs and so 'value' as used in this report does not imply life-cycle value.

It should also be noted that DSO services are highly geographic and as such the revenues shown below will not be available in all areas. Additionally, price competition may reduce the value available from DSO services as widespread FLEX increases.

ELECTRICITY COST SAVINGS AND ANCILLARY SERVICES REVENUES

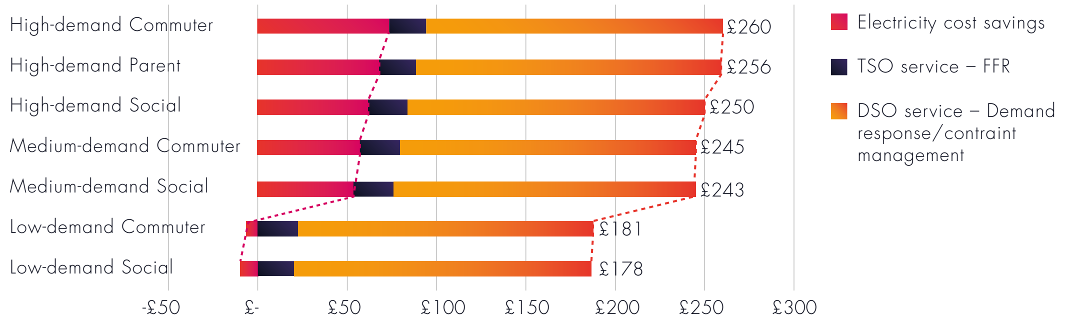


Figure 4.4 – Estimated FLEX values for the considered property types/EV use cases

The estimated FLEX value as a percentage of household bill is shown below in Table 4.5 for each customer type.

Customer type	FLEX value as a percentage of bill
High-demand Commuter	18.6%
High-demand Parent	21.1%
High-demand Social	21.5%
Medium-demand Commuter	21.0%
Medium-demand Social	26.2%
Low-demand Commuter	28.5%
Low-demand Social	44.9%

Table 4.5 – Estimated FLEX values as a percentage of household bill for the considered customer types

Key findings from the modelling regarding electricity cost savings are as follows:

- Value from peak shifting is sensitive to consumer type:

  Based on current wholesale cost profiles and network charges, savings from peak shifting is a smaller component of the overall value stack compared to ancillary services revenues. The property demand and consumption patterns, as well as surplus solar available at the property, have a high degree of sensitivity on cost savings that can be achieved.

- Value from peak shifting tempered by additional energy imports for ancillary services:

  The additional energy cost for providing ancillary services has a material effect of reducing the savings in energy costs from peak shifting. In some cases, this can be higher than the annual savings in energy costs.

- Low demand/EV utilisation customer types are only attractive for DSO services:

  The value opportunity from peak shifting and smart charging is low for customer types with low demand and low EV utilisation levels, and the value stack is heavily reliant on DSO services. For such customer types, if DSO service opportunities are not available, then there is little benefit from co-ordinated FLEX at the household level. Moreover, if the EV is available for most of the time during the evening peak period, then with the EV by itself performing peak-shifting, an ESS would not be needed for such low-demand consumer types (unless DSO services are available and pursued).

Key findings from the modelling regarding ancillary services are as follows:

- Value from DSO services can be lucrative but is extremely location sensitive:

  DSO services form a key part of the value stack, but are subject to large variance in value depending the local network constraints and service need. WPD's SECURE service offers better value over the year compared to the DYNAMIC service; although the latter has a higher utilisation tariff, the likelihood of utilisation is lower. The right kind of DSO service opportunities appropriate for the domestic portfolio would need to be pursued. If otherwise, revenues from DSO services are not attractive.

- Co-ordinated FLEX can help maximise value from DSO service opportunities:

  A household or a portfolio being able to offer a higher volume with co-ordinated and combined FLEX from the suite of ESS and EV available would be able to maximise value.

- FFR is a less attractive value proposition:

  FFR is a small portion of the value stack, and so may not be worth pursuing given metering, testing and associated administration costs unless the entry requirements are streamlined.

In summary, domestic FLEX is a notable value opportunity, with possible savings of up to £260 p.a. per household under best conditions. Additionally, domestic FLEX offers material peak load shifting potential for the DSO. Modelling based on half-hourly data indicates a reduction of between 35-40% in peak loads on the network compared to the baseline case.

5 PASSIVSYSTEMS DOMESTIC LEVEL MODELLING[5]

5.1 MODELLING APPROACH

PassivSystems have carried out an internal programme of modelling to explore the interrelations between the low carbon assets. The approach is broadly similar to Everoze's domestic-level modelling but is more closely tied with PassivSystems, models which will be used in the field trial. PassivSystems were also keen to understand the more detailed relationships between the assets and directly explore some of the elements of coordinated control that are going to be tested live in the field trial.

The modelling approach first involved generating typical demand profiles for the technology assets considered under MADE when operating in isolation. The asset configurations used in the modelling align with the high-demand, high EV use (Commuter) customer type used in Everoze's domestic level techno-economic modelling. These baseline individual profiles were then layered to obtain a typical baseline whole household system demand profile, which was then analysed in order to gain awareness of potential demand problems, and to obtain insight into potential flexibility which could offer a solution to these problems. Modelling was carried out across a whole year on a half-hourly basis, using 2018 data.

Three initial optimisation methods were modelled to help gain insight into examples of control strategies that might be used during the trial:

1 **Optimisation Method 1: Delayed EV charging**
Introduction of a delay in EV charging to a time when electricity becomes cheap, i.e. there is reduced network demand.

2 **Optimisation Method 2: Switching from heat pump to gas boiler.**
Refrain from using the heat pump whilst EV charging is in operation, instead meeting the heating demand of the home through the use of the gas boiler.

3 **Optimisation Method 3: Constraining EV Charge Power**
Charge the EV at a reduced power over a longer time period.

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[5] The information in this section are taken from the following report: MADE: PassivSystems Initial Modelling and Research Report,PassivSystems, August 2019

5.2 MODELLING RESULTS

Figure 5.1 and Figure 5.2 show the modelled baseline demand profile for an example winter and summer day, respectively. It should be noted that, in these figures, 'Heat Power' refers to the electrical power consumed by the heat pump.

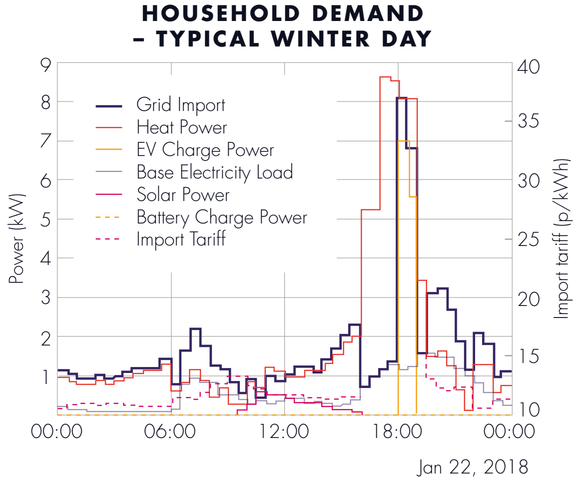
HOUSEHOLD DEMAND – TYPICAL WINTER DAY

Figure 5.1 – Baseline profile, typical winter day

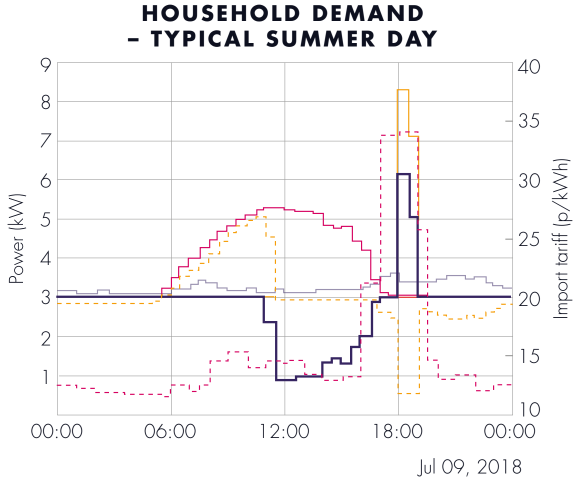
HOUSEHOLD DEMAND – TYPICAL SUMMER DAY

Figure 5.2 – Baseline profile, typical summer day

The following was observed through analysis of the baseline profile:

- Due to the nature of the EV Commuter use profile, without smart charging, EV charging is likely to fall during times of increased electricity import costs, corresponding to times where there is high demand on the network. This timing, coupled with the high EV charge rates, mean that this is both expensive for the consumer and likely to lead to potential network problems.
- EV charging is a significant load compared to other household loads; EV charge power can reach up to 7kW, whilst heat pump power is constrained to 2kW, battery charge power is constrained to 3.3kW and base household electricity consumption has a maximum of 1.8kW over the year. This suggests that simply shifting the EV charging to a different time or postponing the operation of other energy assets within the home whilst the EV is charging is not likely to be a sufficient solution to mitigate potential network overloads if high EV uptake occurs. Instead, one possible solution includes inter-home coordination, where the EV load of one household could be compensated by the delaying of EV charging or switching to gas boiler use in multiple other households. Alternatively, another potential solution includes a constraint on EV charge rates. Reducing the EV charge rate would potentially make it possible to compensate for the EV charging load through intra-home coordination of assets, since the loads would be more comparable.
- Due to low solar generation coupled with the assumed simplistic domestic battery charging behaviour (charging when there is excess solar generation, discharging when there is excess household consumption), the battery is used very little over the winter.

The following can be observed from implementation of the three optimisation methods outlined previously:

Optimisation Method 1

Delayed EV charging

It can be observed that the EV charging moves entirely away from the import tariff peak, which leads to a reduction in associated import costs of approximately £180 over the year. However, a small increase in peak daily electricity demand during winter is observed. Since the household heating demand is met by the boiler during the import tariff peak and outside of this peak, it is met by the heat pump, shifting the EV charging outside of this time led to the heat pump and EV charger operating simultaneously, explaining this small increase. This is unlikely to be an issue on a house by house basis, but may present problems at feeder level if this effect occurs in multiple homes.

Optimisation Method 2

Switching from heat pump to gas boiler

It can be seen that there is little effect on annual cost to the consumer, with an increase of £13 across the year in the optimisation case. This is largely due to the fact that EV charging commonly takes place during times when the import tariff is expensive, and thus the gas boiler is used instead of the heat pump during this time anyway, coupled with the fact that EV charging is typically quite short (less than two hours) in the modelled scenario. However, this method of optimisation could be used in conjunction with Optimisation Method 1, to enable the cost saving benefits of shifting EV charging away from times of peak import tariff, whilst preventing the increase in winter peak import loads.

Optimisation Method 3

Constraining EV Charge Power

It can be observed that this optimisation method notably reduces the homes' demand peaks. This allows for the coordination of assets also has a much bigger role to play as the relative power consumption levels of the EV, battery and heat pump are more comparable.

5.3 SUMMARY

The modelling results demonstrate that there is benefit, both in terms of peak demand reduction and consumer cost savings, from demand management and coordinated control of multiple energy assets. This is in line with findings from Everoze's techno-economic modelling, which was also conducted at household level.

The modelling also demonstrates that potential consumer cost savings of up to nearly £200 can be achieved through implementation of simple example demand management interventions. It is expected that these example control strategies will be used in combination during the trial to unlock greater value, in conjunction with additional strategies, such as charging the battery when the electricity price is cheap and vehicle to grid (V2G) services. In line with this, Everoze have demonstrated that there is potential for further savings from flexibility and coordination between assets.

A key output from this modelling is the observation that, from a DSO perspective, EV charging presents a sharp spike in demand, which dominates over the demand from other energy assets within the home. This means a key next step for the MADE trial is to investigate methods where the EV charging can be both delayed from the period of peak demand and spread out over time (a combination of optimisation methods 1 and 3). In this scenario, the coordination of assets also has a much bigger role to play as the relative power consumption levels of the EV, battery and heat pump are more comparable.

This modelling work has provided key insights into the diverse load profiles of each low carbon asset and how the balance changes significantly through the seasons, which will allow us to construct a meaningful field trial to explore the value of asset coordination.

CONSUMER COST
SAVINGS OF UP
TO NEARLY **£200**
CAN BE ACHIEVED

6 LOCAL NETWORK MODELLING

6.1 MODELLING APPROACH

Delta-EE's primary modelling focus has been to draw on the outputs from the household level modelling and simulate the impact of the LV network to understand the level of constraint. This modelling uses outputs from the domestic level modelling conducted by Everoze, outlined in Section 4 of this report. A model has been created which uses the electricity demand and export profiles to create a demand profile at the feeder level. The model calculates demand diversity across the total number of households on a feeder based on the total number of customers, and the proportion of customers with the new technologies installed (representing the market penetration).

The feeder is assumed to have been sized based on the after diversity maximum demand (ADMD) of a feeder consisting of the average UK home (that has no solar PV, heat pump or EV). This allows for the feeder limit to be calculated, and hence the number of occurrences where demand exceeds this limit.

Figure 6.1 shows the model flow chart for the local network modelling, including required inputs and outputs.

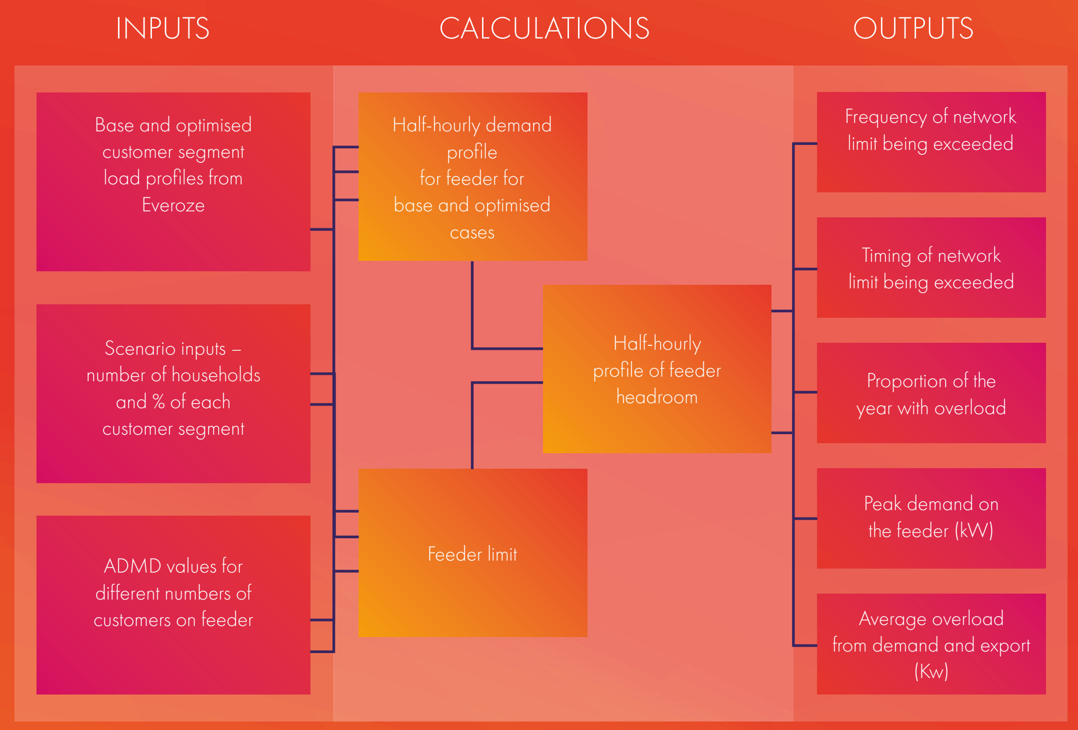

Table 6.1 – Local network modelling flow chart

The feeder level modelling performed as part of this task is a high-level analysis necessitating a number of assumptions and resulting limitations:

- Spatial variations:

  There is a large range in network capacity/headroom, as well as voltage issues across UK feeders. Therefore, actual effects will be very location-specific and this is not captured within the modelling.

- Load profiles:

  There are only two profiles available for each month in the Powering the Nation dataset – weekday and non-working day. This means there is the implicit assumption every weekday in every month is identical. These profiles also do not capture extremes in temperatures. The load profiles used are also built on the average of a sample of four to eight houses for each customer segment, so some diversity is already built into these.

- Diversity factors:

  Diversity is fairly well characterised for houses with no LCTs. The effect of the combined operation of EVs, heat pumps, solar PV and domestic battery systems is uncertain and this uncertainty increases once automation/optimisation is included. This is a particularly important consideration if the optimisation algorithms respond in a similar manner to price signals, as this will act to decrease diversity. Applying a single diversity factor across the whole electricity profile was a simplifying assumption, but appropriate for the level of this analysis.

- Customers per feeder:

  We have assumed there are 34 houses to a feeder. This is based on expert input and existing Delta-EE analysis on the average number of customers per feeder in a suburban setting.

Feeder composition of household stock affects the results significantly. Three different scenarios were used for our modelling as presented below:

- Exclusively high demand network:

  Houses in a given area tend to be of similar sizes and have similar occupancy profiles, especially in older areas of housing. This means that some feeders may consist exclusively of higher demand customers. These networks will likely be the first to experience constraints caused by deployment of EVs and other technologies, due to larger houses being more likely to have off street parking and have more wealthy occupants.

  We look at two sub-scenarios:

  + All EVs are used for commuting (i.e. lower diversity in demand)

  + Even mix of EV profiles

- Even mix of customer segments:

  In urban areas, a single feeder may be serving a wide range of customer segments. This scenario investigates an even mix of both customer segments and EV usage profiles: the maximum amount of diversity possible within the limitations of this model.

- Medium and low demand network:

  This scenario investigates a feeder supplying only low and medium demand houses.

6.2 MODELLING RESULTS

6.2.1 BASE CASE RESULTS

The following results regarding the base case scenario were deduced from the local network modelling:

- The results of the modelling show that higher penetration rates of LCT results in significant overloading of the LV electricity network.
- If more than 50% of homes served by the same LV feeder were to have an EV, a heat pump and solar PV the thermal limit of the feeder serving the homes in that area is likely to be breeched.
- At higher penetration levels (e.g. if 80% of homes have the aforementioned technologies), the feeder thermal limit is breeched significantly (e.g. double the limit of a 70kW feeder), and regularly (2-5% of the year.
- Assumptions around the customer types present on a feeder has a significant effect on if, or to what extent, overloading occurs. Higher levels of penetration of LCT can be achieved if there are more lower demand customers on a feeder.
- ADMDs and feeder capacity varies significantly and has a large impact on these results.

6.2.2 OPTIMISED CASE RESULTS

The following results regarding the optimised case scenario were deduced from the local network modelling:

- The optimisation of demand and export at the household level reduces the overloading at the feeder level at low to medium penetration levels, moving consumption away from current peak times.
- However, overloading of the feeder in the optimised case still occurs at higher technology penetration levels and at extremely high levels can occur more regularly than in the base case. This is due to households optimising their consumption based on the same price signals resulting in low diversity of demand and coincidences of peak power.
- In the optimised scenarios, many more overload incidents occur at night (e.g.10pm), as this is when peak demand has been shifted in response to current market mechanisms identically across homes.
- There are occurrences in the optimised case where the thermal limit of the feeder is breeched due to export of power from battery and PV systems. This tends to be between 3-4pm, in response to high market prices.

6.2.3 KEY CONCLUSIONS

The following key conclusions can be drawn from the modelling results:

- Network constraints could be significant by the mid 2030s without optimisation of demand.
- Optimisation of household energy demand in many cases reduces the load on the network. At technology penetration levels of less than 50%, optimisation at the household level to existing price signals reduces occurrences of feeders being overloaded. Beyond this point, price signals will need to be altered to incentivise behaviour that reduces the aggregated loads on feeders. For example, price signals will need to be structured in order to incentivise.
- Staggering EV charging to avoid automated responses causing night time peaks in demand.
- Flattening load profiles can help to increase network utilisation.
- Feeder capacity can vary significantly and exact effects are likely to be location-specific. This has a large impact on the occurrences and extent of network limits being exceeded and should be investigated further.
- The largest load is caused by EV charging. Effective EV smart charging strategies will therefore be key to reducing the likelihood of overloading the network.
- Further research should be done to better assess the impact of diversity in demand on these results, and to assess a broader range of ADMD conditions based on real network data.

OPTIMISATION OF **HOUSEHOLD ENERGY DEMAND** IN MANY CASES REDUCES THE LOAD ON THE NETWORK.

7 WHOLE-SYSTEM MODELLING[6]

Imperial have utilised their Whole-electricity System Investment Model (WeSIM) and Load Related Expenditure (LRE) model to determine the whole-system benefits of the MADE concept. This section provides a summary of this modelling work, extracted from Imperial's MADE project interim report. The whole-system benefits of MADE concept have been assessed using two scenarios for the GB power system: Baseline and High uptake, and for three time horizons: 2025, 2030 and 2035. It should be noted that these benefits do not consider the costs of coordinated control system implementation, as such, these present the best case views of the benefits. Further details on these costs will be developed as part of the trial.

7.1 WHOLE-SYSTEM BENEFITS OF THE MADE CONCEPT

The system benefits of a large-scale deployment of the MADE concept across the considered scenarios are shown in Figure 7.1. Cost savings are reported as annual values, consisting of annual operating costs and annualised investment costs for different asset types. The results suggest that the flexibility delivered via MADE solutions can achieve system benefits in the order of billions of pounds per year.

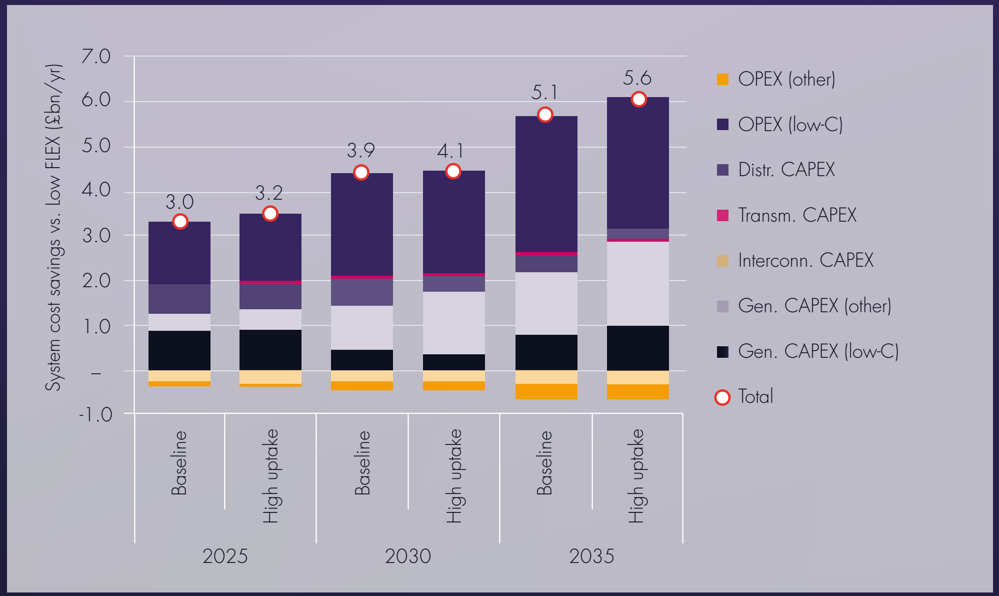

Figure 7.1 – System cost savings driven by MADE concept across scenarios

The main categories of MADE-enabled cost savings include:

- Reduced investment cost of low-carbon generation:

  Distributed flexibility allows cheaper sources of low-carbon electricity (e.g. solar PV) to be integrated more efficiently, and therefore to displace other low-carbon sources while reaching the same carbon target.

- Reduced investment cost of conventional generation:

  Flexible resources can be very effective at reducing peak demand, and therefore greatly reduce the need to maintain a high volume of peaking generation capacity to secure a sufficient generation capacity margin – and the resulting security of supply.

- Reduced investment cost of distribution networks:

  Highly distributed flexible resources included in the MADE concept can help reduce the loading level of local distribution grids, and therefore significantly decrease the requirements to reinforce distribution grids in order to cope with an increase in electricity demand.

- Reduced operating cost of low-carbon generation:

  Flexibility can also displace the output of low-carbon generation with relatively higher operating cost, such as biomass, which is then replaced by lower-cost generation, such as solar PV.

Benefits are significant and can exceed £5.6bn per year in the 2035 horizon with the exclusion of coordinated control and service costs. System benefits have been calculated both with and without V2G services. The results are shown in Table 7.2, suggesting that not including V2G would reduce the overall benefits by £0.3-0.7bn per year.

Scenario	**Year**	**System Benefits (£bn/yr)**	
		With V2G	Without V2G
Baseline	2025	3.00	2.68
	2030	3.94	3.38
	2035	5.06	4.41
High uptake	2025	3.23	2.91
	2030	4.06	3.50
	2035	5.64	4.99

Table 7.2 – Benefits of MADE concept with and without including V2G services

THE FLEXIBILITY DELIVERED VIA MADE SOLUTIONS CAN ACHIEVE SYSTEM BENEFITS IN THE ORDER OF **BILLIONS OF POUNDS PER YEAR**.

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[6] The information and graphics in this section are taken from the following report:
MADE Project Report - High-level assessment of the benefits of large-scale deployment of the MADE concept, Imperial College Project Team, June 2019

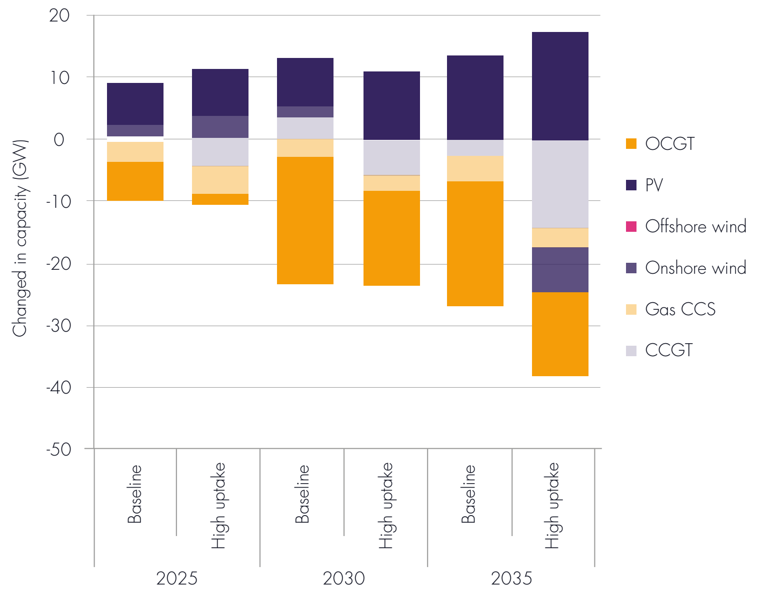


Figure 7.3 – Changes in generation mix driven by the MADE concept

Figure 7.3 illustrates how the additional flexibility unlocked through MADE concept affects the cost-optimal generation mix, and delivers a more cost-effective portfolio of low-carbon and conventional generation technologies. MADE allows for more low-cost solar PV to be connected to the grid, as its integration becomes less challenging, while at the same time displacing the more expensive carbon capture and storage (CCS, and in some cases onshore wind) generation. The capacity of conventional generation (OCGT and CCGT) is in general significantly reduced as the result of enhanced flexibility.

7.2 DISTRIBUTION NETWORK BENEFITS OF THE MADE CONCEPT

Significant distribution network reinforcements could be needed to accommodate rapid uptake of EVs and HHPs. Its effect could increase the total cumulative expenditure on distribution networks by up to £50bn by 2035 (or £1.8 billion per year in annualised terms). According to an earlier analysis by Imperial College, the total replacement cost of the entire GB distribution network is estimated around £100bn, which makes the £50bn reinforcement cost even more prominent.

Utilising distributed flexibility, in particular using smart resources such as EVs and HHPs, could mitigate the impact of electrification of heat and transport on distribution network reinforcement cost. In order to assess the GB distribution network reinforcement requirements driven by heat and transport electrification and the related impact of distributed flexibility, we have run the scenarios considered earlier in our detailed distribution network model (LRE), in order to investigate the implications of high EV and HHP uptake on necessary network upgrades across different voltage levels, asset types and DNO areas.

Figure 7.4 shows the effect of MADE-enabled flexibility on annualised GB network reinforcement cost for the scenarios analysed in this report. Cost savings in Figure 7.4 are broken down according to asset types, voltage levels and reinforcement drivers as follows:

- **LV-I** Low-voltage network reinforcement driven by thermal loading;
- **LV-V** Low-voltage network reinforcement driven by voltage constraints;
- **DT** Distribution transformers;
- **HV-I** High-voltage network reinforcement driven by thermal loading;
- **HV-V** High-voltage network reinforcement driven by voltage constraints;
- **PS** Primary substations;
- **EHV+** Extra high-voltage;
- **GT** Grid transformers.

It should be noted that the counter-factual to these savings is a significant increase in DNO reinforcement cost (mentioned earlier), rather than current levels of DNO reinforcement spend.

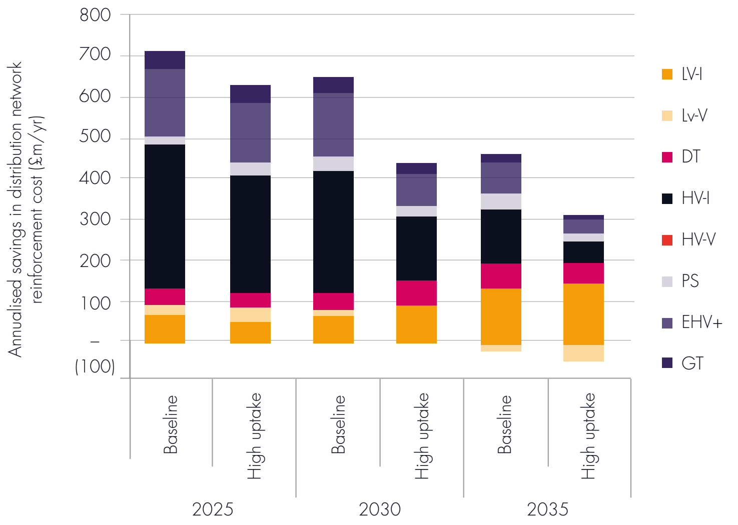
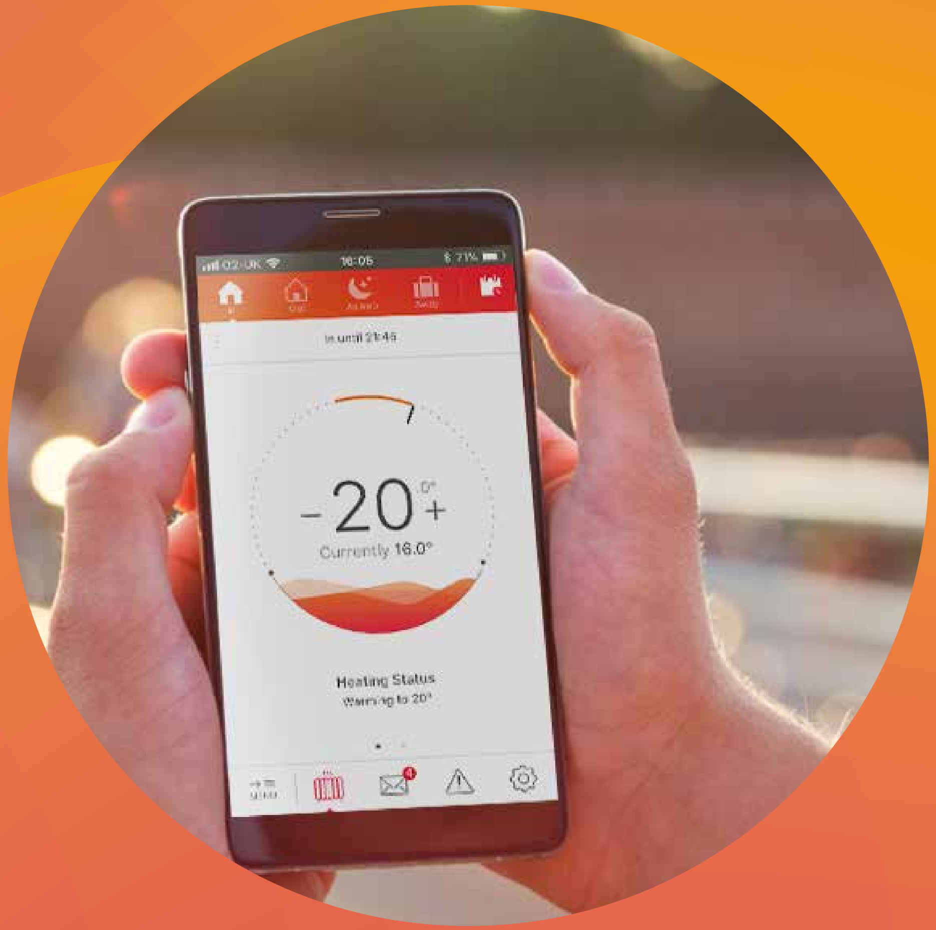


Figure 7.4 – Breakdown of annualised savings in network reinforcement cost driven by the MADE concept across voltage levels and asset types

The results show that the distribution network benefits of distributed flexibility can reach up to around £700m per year in annualised reinforcement cost, and are spread across LV, HV and EHV levels. Reinforcement cost savings diminish when looking further into the future to around £300-450m by 2035, which results from a very high penetration of EVs and HHPs assumed in that time horizon, so that energy requirements become more prominent than power requirements. Nevertheless, the potential savings are still substantial even at high penetrations, and are combined with an increased potential for whole-system savings.

8 CONFLICTS AND SYNERGIES

For the MADE concept to be successful, it is essential to analyse the conflicts and synergies between DNO/DSO and ETO/ESO. The project has conducted an initial review and analysed the work that has been completed from research by Imperial College (summarised in Cost-Effective Decarbonization in a Decentralized Market, IEEE power energy magazine, March 2019) on the implications of managing synergies and conflicts between local and national system objectives and the Low Carbon Networks Fund (LCNF) funded Low Carbon London Project.



Through analysis, it has been identified that the services delivered by flexible distributed energy resources (DERs) could bring significant benefits to several sectors of the electricity industry, including distribution networks, transmission networks, and generation system operation and investment. However, energy supply, transmission and distribution networks are operated by different entities with a level of coordination that is currently limited.

Rather than using DER-based services to maximise whole-system benefits, individual entities tend to use these resources for maximising their own benefits and do not consider the impact it has on other entities. Managing synergies and conflicts among the distribution networks, transmission networks, and energy suppliers as well as EU-wide decarbonisation objectives when allocating

DER flexibility will be critical for the optimal development of the MADE concept system. Consequently, stronger coordination will be needed between system operators at the transmission and distribution levels. This coordination will enable the use of all available flexible resources while managing synergies and conflicts across the different networks.

A whole-system approach improved coordination between DNOs/DSOs and electricity system operators (ESOs)/electricity transmission operators (ETOs) will be required for operating the system and managing future networks at maximum efficiency.

One of the main challenges within the second phase of MADE is to identify and address decentralisation that focuses on local objectives only, rather than minimizing whole-system costs. Decisions may be made by many different entities; guiding their decision-making processes through appropriate policies and commercial frameworks represents a very challenging task that MADE aims to address with recommendations.

Through MADE, efficient market designs will be considered and recommend to reflect the impact of any participant's decisions not only on the local costs but also on wider system costs. It's essential for MADE to consider this, otherwise the overall system costs may be higher than necessary and the need to understand how these decentralised decisions can also be part of the short-and-long-term optimum decisions from the whole-system perspective.

9 MADE CONTROL[7]

9.1 SYSTEM COMPONENTS

Figure 9.1 displays a diagram of the system components considered under MADE.

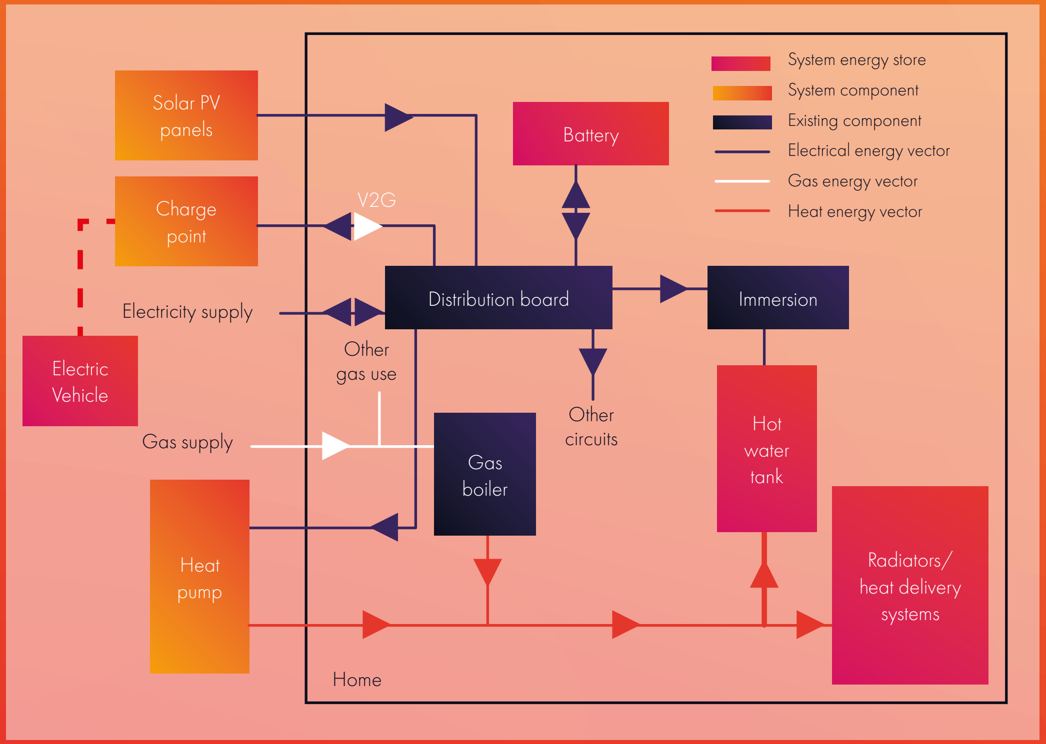


Figure 9.1 – MADE system components

Controlling multiple assets in a coordinated way is difficult; there are multiple trade-offs and decisions to be made. PassivSystems' optimisation technology can solve this challenge in a quantitative way, so at the core of the physical deployment will be a PassivSystems hub which runs optimisation algorithms to control the assets, as well as gathering monitoring data to send to the PassivSystems servers.

9.2 SYSTEM ARCHITECTURE

The project will utilise PassivSystems' existing energy management platform, with the addition of new components for integration with assets that are new for this project.

A logical view of the system architecture is shown below in Figure 9.2.

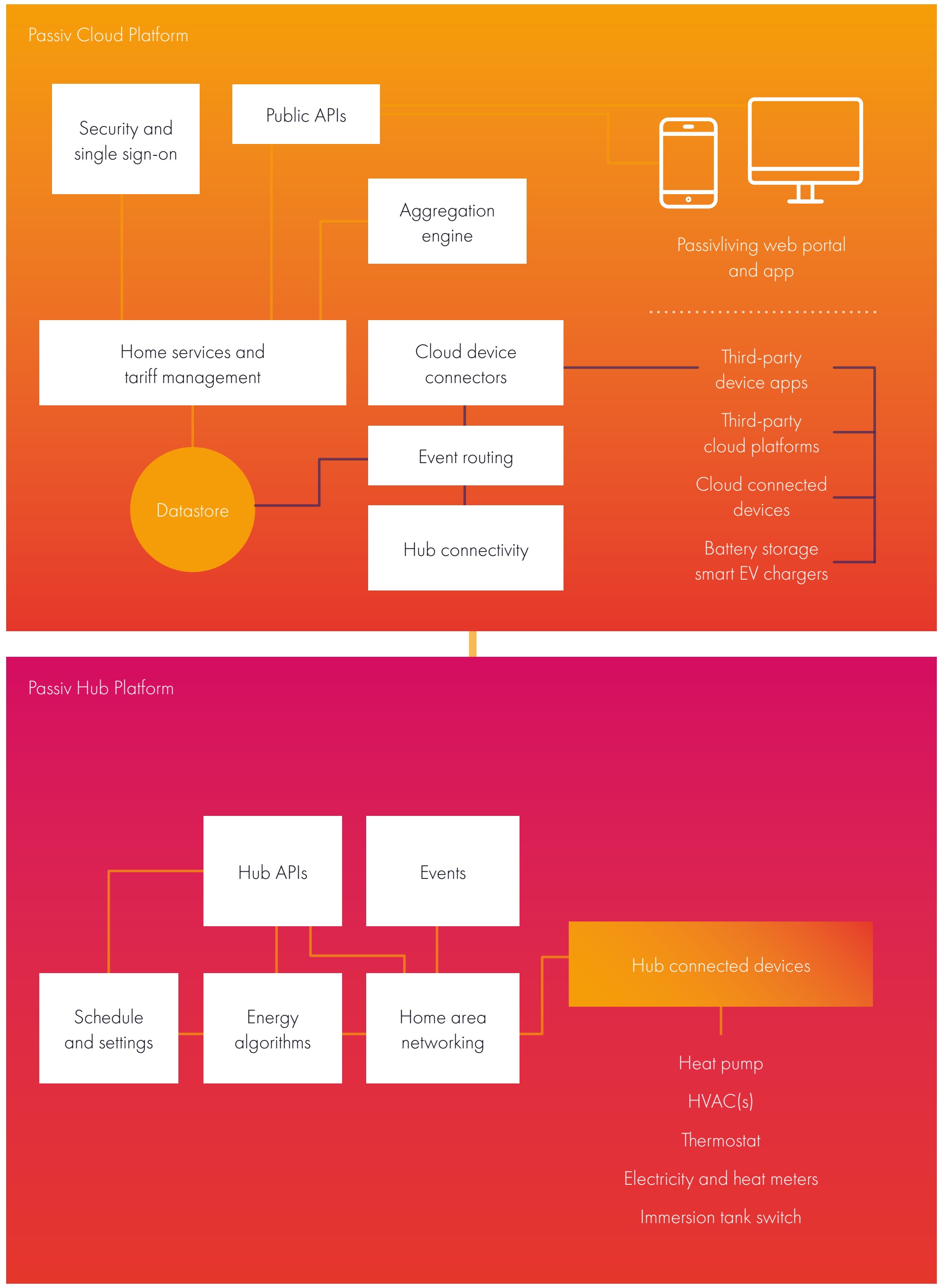


Figure 9.2 – MADE system architecture

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[7] The information and graphics in this section are taken from the following report: MADE High Level Design, PassivSystems, May 2019

9.3 MADE CONTROL – FIELD TRIAL

PassivSystems have developed an initial design for the field trial and the use cases that will be explored over winter 2019-2020 using the deployed physical assets. Our general approach is to explore in-home factors for the multi-asset, multi-vector scenario, rather than factors that affect multiple homes, as a small scale field trial is unlikely to provide definitive answers to the latter.

OUR GENERAL APPROACH IS TO **EXPLORE IN-HOME FACTORS** FOR THE MULTI-ASSET, MULTI-VECTOR SCENARIO

9.3.1 PHASE 1: BASELINE OPERATION

For the first part of the field trial, assets will operate somewhat independently and this will provide baseline data for later comparison.

Flat electricity tariff

We expect that participants will initially be on a flat electricity tariff that provides no incentives to shift electricity from peak times. Operation is expected to illustrate how demand coincides in the early evening.

High fossil fuel price

The HHP controls will be configured with a high price for the fossil fuel boiler to reflect the future scenario of substantial decarbonisation (so that as high as possible a proportion of the heat demand is provided by the heat pump). Against this pricing, HHP operation will be optimised by the system to minimise running costs for the user and maximise heat pump efficiency.

Solar optimisation

The heat pump will be optimised to utilise available solar generation (and recognise that it is free), but will not otherwise be coordinated with the battery. An alternative baseline scenario we might consider is no solar awareness for the heat pump (i.e. it assumes electricity it consumes is a fixed price).

Simple automatic battery control

The batteries will be controlled by Sonnen's internal "automatic" control algorithm which charges the battery when there is net household production (i.e. excess PV generation that would have been exported), and discharges when there is net consumption. The battery will thus react to heat pump operation, and in effect the heat pump will have priority on the solar generation.

Default EV charger behaviour

The EV charger will be used "out of the box", however the consumer decides, and the consequences will be monitored.

Monitored data will be collected from this phase and analysed to produce conclusions as to likely load profiles in the baseline scenario. These results will be compared with modelling, and further modelling work used to extrapolate these results to the country as a whole (i.e. used to refine previous models).

9.3.2 PHASE 2: NATIONAL-SCALE GRID DRIVERS

The next step is to construct a scenario where assets in the home react to national-scale grid drivers (but assets within the home are largely uncoordinated with each other). This will explore the impact of "selfish algorithms", where multiple assets take advantage of cheap electricity prices (for example) causing stress on the local distribution network.

Variable ToU electricity tariff

We propose that all trialists simulate the "Octopus Agile" tariff as this is the most advanced tariff in the market today and most representative of future price variations (as prices are determined by the day-ahead electricity wholesale market).

Export tariff

If possible we will suggest that trialists simulate the "Outgoing Octopus" tariff which pays a variable rate for electricity exported to the grid. We believe that export tariffs are going to become more widespread with the Smart Export Guarantee coming in from 2020.

HHP optimisation

Heat pump operation will be optimised against the variable rate tariff, so that heat will be stored in the fabric of the house during low tariff periods, and perhaps the fossil fuel boiler will be used during high tariff periods; the strategy will be determined by optimisation calculation.

Simple battery control

On top of the "automatic" behaviour, we will inject commands to charge if the grid import price is below a certain threshold or discharge when the export price is below a threshold.

Immersion control

We will inject simple commands to turn on the immersion heater if the grid import price is below an appropriate threshold such that it is the cheapest way of producing hot water.

EV charge control

The occupiers will be encouraged to set up rules on their smart charger to take advantage of the ToU tariff in a relatively simple way.

We hope to demonstrate from analysis of the monitored data some of the consequences of cheap rate electricity, such as causing simultaneous asset activity which results in higher grid stresses than the baseline case.

9.3.3 PHASE 3: IN-HOME ASSET COORDINATION

PassivSystems will develop algorithms which coordinate assets within the home to take best advantage of the variable availability of cheap electricity, the different storage potential of the assets, and the various patterns of consumption needed by the occupiers. These will calculate the best strategy for the householder in terms of minimising running costs against the variable tariffs. The battery will be put into "manual" mode in circumstances when the algorithm determines that it can do better than the default "automatic" mode.

The purpose of this phase will be to find out how the patterns of asset operation change when they move from uncoordinated to coordinated control within the home, and whether this makes the impact on the local grid bigger or smaller.

9.3.4 PHASE 4: LOCAL GRID INTERVENTIONS

In this final phase, we will identify some key grid problems (for example, times of peak load), and will design some interventions which demonstrate that an inter-home coordination system could mitigate some of the problems. This could, for example, involve pushing down to the control algorithms a whole-house maximum power constraint which is applied across the set of flexible assets, and might for example result in more pre-heating by the heat pump and a transition to gas heating at the time that the EV is plugged in and the sun has gone down. This phase is expected to take place towards the end of the trial, around March 2020.

THESE CASES WILL BE EXPLORED OVER **WINTER 2019-2020**

10 BUSINESS MODELS[8]

The energy landscape is rapidly evolving and moving from the traditional centralised model (central power generation) to one that is decentralised, more customer centric and lower carbon. This transition is seeing a lot more value being moved downstream and this is resulting in new ways for domestic customers to access these value streams.

As part of MADE, Delta-EE have identified customer propositions for business models which could be developed following a large-scale deployment trial. These propositions are built upon a well-used framework for developing business models and customer propositions, and build on insight taken from studying similar business models.

The propositions identified by Delta-EE are as follows:

1. All inclusive

All energy services (heating, personal transport and other energy needs), provided for a single monthly fee.

This option focuses on minimising the cost of buying electricity from the grid by maximising self-consumption. The main aim of this business model is to deliver heating to the home using electricity generated by the solar panels. Control strategy of the heat pump would predict when heating is needed and pre-heat the home using available electricity if appropriate.

If insufficient electricity is generated, then cheap electricity could be bought from the grid or heating could be delivered via the boiler. Any excess electricity could be used to charge the EV, supplemented by grid electricity which is expected to be sufficiently cheap over-night. Excess stored electricity could also be sold back to the grid at times of high demand.

2. Buying enhanced control

Company optimises energy demand across technologies and pays income to customer.

This option provides flexibility to the customer who can include whichever technologies they have or want to buy and has no tie-in to a contract. The main feature of this business model is the smart controller hub which optimises energy demand for heating across heat pump and boiler and optimises EV charging based on pricing signals or other choices given by the household (i.e. it could be to minimise cost or CO^2 emissions).

The customer is responsible for buying the technologies and energy separately, and the company delivers energy savings compared to each technology being controlled separately. If the package includes battery storage, additional revenue can be gained from selling electricity back to the grid at times of high demand and the customer is paid credit for each of these DR events.

3. Minimising peak demands

Balancing electricity demand over the home to reduce peak demand, in return for a cheaper tariff.

This option is the closest extension to the FREEDOM project, testing the ability of control across the house to minimise costs and reduce peak demand. The main aim of this business model is to minimise overall power draw of the house by controlling the heating and EV charging assets without a requirement for storage and PV. Solar PV and storage are not included in this proposition. This tests the performance of the HHS and EV combination in homes where PV and storage are not possible. Different combinations of technologies may be suitable for different households.

HHS operation is controlled to optimise the efficiency of the heat pump, overall cost on a dynamic ToU tariff, and ideally also minimising gas usage. EV charging is optimised for times of low electricity demand in the home and cheap grid electricity. Where chargers are compatible, some stored electricity in the EV could also power the heat pump operation.

A summary of these customer proposition options is shown on the next page in Table 10.1.

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[8] The information and graphics in this section are taken from the following report: MADE Project Interim Report, Delta-EE, August 2019

	Option 1 All inclusive	**Option 2** Buying enhanced control	**Option 3** Minimising peak demand
Technologies included	Heat pump, gas boiler, EV, solar pv, battery storage, smart controller hub.	Smart controller hub plus any combination of heat pump, gas boiler, EV, solar pv, battery storage.	Heat pump, gas boiler, EV, smart controller hub.
Purchase / ownership of tech	Leased at no upfront cost to customer.	Bought upfront by customer (or through finance arranged by customer).	Bought upfront by customer (or through finance arranged by customer).
Energy supply	Included within monthly fee.	Bought separately by customer.	Included but paid per unit energy used.
Contract	Monthly fee covers lease of technology, energy supply, MS&I. Approx. five years (could offer choice).	No monthly fee, no minimum contract length.	No monthly fee, no minimum contract length.
Customer value streams	Monthly fee which is an acceptable price to customer, easier budgeting, peace of mind.	Energy bills are reduced by smart control hub. Credit paid back from any DR revenue.	Cheap flat rate energy price (not being exposed to ToU variation).
Customer value streams	Minimising cost of electricity through self consumption and buying at cheap times (company keeps costs savings), selling electricity to grid at peak times.	Sale of smart controller hub DR revenue from selling electricity back to grid at times of high demand.	Minimising peak power draw over home (no current value in this in UK), minimising cost of heating and charging EV via dynamic ToU signals, DR revenue - turning down demand.
Risks	Low for the customer, except for perception of entering a contract. Main risks taken on by company.	Low if the customer was seeking to buy these technologies already (but long payback period if all tech bought).	Low if the customer was seeking to buy these technologies already.
Target customer	Customers who seek low carbon heating and personal transport.	Customers who own or would like low carbon heating and personal transport.	Customers who are looking to buy low carbon heating and personal transport.
Most suitable provider	Energy service provider (could be energy supplier, manufacturer or other).	Controls company.	Energy supplier, DNO.

Table 10.1 – Summary table of customer proposition options

In addition to understanding potential future business models, Delta-EE have also considered a proposition for participants if a large-scale deployment trial was to take place, aiming to test how its suite of technologies interact and can access flexibility value streams as they emerge or increase in the future.

The assumed fixed aspects of the trial:

- All households will have all technologies:

  HHS (heat pump and boiler), EV and charger, solar PV and battery, control hub;

- Households will pay for or already own heat pump, boiler, solar PV and battery:

  Household will be provided with EV, charger and control hub;

- Trial length will be two years.

- No further relationship or contract is intended to be offered after two year trial.

The options for a trial proposition are limited by the requirements on which technologies must be included, and that the customer must pay for them. The main variation between different options are whether energy supply is included, and how the customer is financially incentivised to participate. A summary of the identified potential trial proposition options can be seen below in Table 10.2.

	Option 1: Fixed monthly cost	**Option 2:** Low price energy tariff	**Option 3:** Credit payment	**Option 4:** Social housing
Technologies included	Heat pump and battery storage (paid for by customer), Gas boiler and solar PV (assumed customer already owns) EV (leased to customer for free), smart controller hub (assume given for free)			
Purchase of tech*	Bought upfront by customer		Bought by social housing provider through grant funding	
Energy supply	**Included:** within fixed monthly fee	**Included:** paid per unit used	Bought separately by customer	Bought separately by customer
Contract	Length of trial (two years) **Guarantees include:** sufficient level of comfort delivered, sufficient mileage in car when required			
Customer value streams	• Low fixed monthly price for energy (based on level of existing usage or similar) • MS&I included • Lease of EV for free	• Low price tariff for energy • Lower energy demand (due to increased self consumption) • MS&I included • Lease of EV for free	• Monthly or periodic credit payment for being involved in the project Lower energy demand (due to increased self consumption) • MS&I included • Lease of EV for free	• Monthly or periodic credit payment for being involved in the project • Lower energy demand (due to increased self consumption) • MS&I included • Lease of EV for free
Company value streams	Experiments demonstrate value of: optimising dynamic ToU, self-consumption of PV, selling electricity back to grid via DR			
Risks	• Financial benefit to customer is unlikely to cover capital cost of technologies • Value streams cease to exist after trial			
Target customer	Wealthy/high income households who are attracted by all-electric home or minimising environmental impact			
Partners needed	Energy supplier, provider of EVs	Energy supplier, provider of EVs	Provider of EVs only	Provider of EVs, social housing provider

Table 10.2 – Summary table of trial proposition options

11 CUSTOMER ENGAGEMENT[9]

As part of MADE, Delta-EE carried out customer research with 750 UK car owners. This exclusively commissioned customer research was carried out in order to better understand current views around EV ownership (and usage patterns) as well as third party control of EV charging. The research was carried out via an online survey during May 2019, with a panel of UK adults that is close to representative of the broader UK population.

The panel contained:

52	**57**	**67**	**150**
Respondents that own a fully electric vehicle	**That own a plug-in hybrid vehicle**	**That own a hybrid (can't be plugged in)**	**Respondents that own solar PV**

Depending on the technologies owned, survey respondents were directed to answer different sets of questions. The maximum number of questions answered by any respondent was 38.

The key findings from this survey were as follows:

1 EV charging

The most popular place for charging is at home. Most current EV owners charge their EVs for less than two hours per session. If forced to allow third party control of their EV charging for the purposes of V2G, EV owners are willing to let their batteries discharged to a minimum level of 30%. EV owners are mostly very positive about the idea of having an app to help them control their charging.

2 Third party control

There was a lot of concern around third party control of charging and heating systems across all groups. If third-party management of assets is to be accepted, people still want to feel as if they are ultimately in control at all times and that the third party is helping them save money.

3 EV and solar PV owners are higher income and more engaged

One of the apparent trends in the results is that the EV and solar PV owners tend to be between the ages of 25-49, are more engaged with switching their energy supplier, tend to have higher incomes (over £64k household income/year and own their own homes. They also tend to live in detached homes, which are more likely to have their own driveway (for EV charging) and more roof space, for putting solar PV panels. The majority also are interested in installing a battery system. When asked about their attitude towards the environment, they tend to think they are doing as much as they can to be environmentally-friendly.

4 Those with electric heating are more engaged

Of the survey respondents, 22% said electric heating was their main source of heating. A higher proportion of those with electric heating (including heat pumps) had low emission vehicles, particularly a fully-electric car. Those with electric heating also switched suppliers more often than any other group.

5 The laggards

There was a group of respondents, about 10% of the total, that tended to be older (>50), drive petrol cars and not own solar PV. They were not as interested in being green and do not regularly switch energy suppliers. They also had little awareness of heat pumps or smart appliances or heating controls.

6 Comparing the results of this customer research to other sources

It is apparent that the online survey sample is not a truly representative sample given how much more aware of heat pump technologies the respondents were when compared to the Department for Business, Energy and Industrial Strategy (BEIS) Public Attitudes Tracker (PAT) (47% awareness in our study, versus 25% awareness in BEIS PAT).

Another discrepancy can be found in the number of respondents that actively switch their energy supplier. Data from Ofgem and BEIS indicates that between 15 and 20% of homeowners switched their energy supplier in the last year, whereas our survey results indicate that 43% switched their energy supplier in the last year.

This is likely an artefact of the nature of an online survey, where the respondents are more likely to be informed and tech savvy.

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[9] The information and graphics in this section are taken from the following report: MADE Project Interim Report, Delta-EE, August 2019

12 CONCLUSIONS

12.1 SUPPORTING DATASETS

Previous NIA projects provide a useful data source for information on individual LCTs which may be installed within a home. In particular, the FREEDOM project has enabled PassivSystems to develop an annual forecasting tool, enabling the gas and electricity demands of a HHS to be modelled, in order to provide heat pump demand profiles for use in the MADE modelling. Through the FREEDOM project, PassivSystems have also gained knowledge on consumer acceptance of HHS operation, and therefore what demand management interventions may be acceptable to consumers. This will help to shape the MADE control strategy.

In addition to this, Electric Nation results demonstrate that there is scope for demand management of EV charging, and that ToU incentives can be effective in influencing charging habits. The project also demonstrates that mass uptake of ToU tariffs can lead to further complications surrounding demand on the network, suggesting that coordinated control between households may be required to manage these consequences. Electric Nation has also provided insight into domestic consumer EV charging use, which has been used to develop the EV charging profiles used for the MADE modelling.

However, while these projects provide useful insight into the operation of LCTs in isolation, no previous projects have addressed operation of all the energy assets considered under MADE in combination.

12.2 DOMESTIC LEVEL TECHNO -ECONOMIC MODELLING

Domestic FLEX is a notable value opportunity, with possible savings of up to £260 p.a. per household under best conditions. Additionally, domestic FLEX offers material peak load shifting potential for the DSO. Modelling based on half-hourly data indicates a reduction of between 35-40% in peak loads on the network compared to the baseline case.

The key conclusions regarding electricity cost savings from Everoze's techno-economic modelling at a domestic level are as follows:

- Value from peak shifting is sensitive to consumer type;
- Value from peak shifting tempered by additional energy imports for ancillary services;
- Low demand/EV utilisation customer types are only attractive for DSO services.

The key conclusions regarding ancillary services from Everoze's techno-economic modelling at a domestic level are as follows:

- DSO services form a key part of the value stack, but are subject to large variance in value depending on the local network constraints and service need;
- Co-ordinated FLEX can help maximise value from DSO service opportunities;
- FFR is a less attractive value proposition.

12.3 LOCAL NETWORK MODELLING

The following key conclusions can be drawn from the local network modelling results:

- Network constraints could be significant by the mid 2030s without optimisation of demand.
- Optimisation of household energy demand in many cases reduces the load on the network. At technology penetration levels of less than 50%, optimisation at the household level to existing price signals reduces occurrences of feeders being overloaded. Beyond this point, price signals will need to be altered to incentivise behaviour that reduces the aggregated loads on feeders. For example, price signals will need to be structured in order to incentivise.
- Staggering EV charging to avoid automated responses causing night time peaks in demand.
- Flattening load profiles to increase network utilisation.
- Feeder capacity can vary significantly and exact effects are likely to be location specific. This has a large impact on the occurrences and extent of network limits being exceeded and should be investigated further.
- The largest load is caused by EV charging. Effective EV smart charging strategies will therefore be key to reducing the likelihood of overloading the network.
- Further research should be done to better assess the impact of diversity in demand on these results, and to assess a broader range of ADMD conditions based on real network data.

12.4 WHOLE-SYSTEM MODELLING

Imperial's whole-system case studies demonstrate that there are significant opportunities to deliver significant cost savings by utilising distributed flexibility based on the MADE concept. Potential system benefits increase with the level of penetration of electrified transport and heat as well as with the level of carbon reduction, so that in 2035 the savings could exceed £5.6bn per year. Reduction in system cost occurs through allowing the system to achieve the carbon target with a less costly low-carbon generation mix, which also means integrating more low-cost solar PV, while at the same time reducing the requirements for high volumes of peaking generation capacity and distribution network reinforcements.

Imperial's high-granularity distribution network analysis suggests that there is also a significant potential for distributed flexibility to deliver distribution network cost savings across different voltage levels and asset types, potentially exceeding £650m per year in mitigated reinforcement cost in the 2030 horizon. This is framed in a context of significant additional DNO spend needed to accommodate non flexible LCTs rather than current spend levels.

At very high penetration levels of EVs and HHPs, however, the opportunities for distributed flexibility to avoid reinforcements could become diminished, given that network reinforcement becomes driven by the significant additional volumes of electricity required by new loads rather than their demand usage patterns.

Nevertheless, the potential savings are still substantial even at high penetrations, and are combined with an increased potential for whole-system savings. However, the opportunities for distributed flexibility to avoid reinforcements could become diminished, given that network reinforcement becomes driven by the significant additional volumes of electricity required by new loads rather than their demand usage patterns. Nevertheless, the potential savings are still substantial even at high penetrations, and are combined with an increased potential for whole-system savings.

12.5 MADE CONTROL

Controlling multiple assets in a coordinated way is difficult: there are multiple trade-offs and decisions to be made. PassivSystems' optimisation technology can solve this challenge in a quantitative way, so at the core of the physical deployment will be a PassivSystems hub which runs optimisation algorithms to control the assets, as well as gathering monitoring data to send to the PassivSystems servers. The project will utilise PassivSystems' existing energy management platform, with the addition of new components for integration with assets that are new for this project.

PassivSystems have developed an initial design for the field trial and the use cases that will be explored over winter 2019-2020 using the deployed physical assets. Our general approach is to explore in-home factors for the multi-asset, multi-vector scenario, rather than factors that affect multiple homes, as a small scale field trial is unlikely to provide definitive answers to the latter.

Phase 1

Baseline operation

For the first part of the field trial, assets will operate somewhat independently, providing baseline data for later comparison.

Monitored data will be collected from this phase and analysed to produce conclusions as to likely load profiles in the baseline scenario. These results will be compared with modelling, and further modelling work used to extrapolate these results to the country as a whole (i.e. used to refine previous models).

Phase 2

National-scale grid drivers

The next step is to construct a scenario where assets in the home react to national-scale grid drivers (but assets within the home are largely uncoordinated with each other). This will explore the impact of "selfish algorithms", where multiple assets take advantage of cheap electricity prices, for example, causing stress on the local distribution network.

From analysis of the monitored data, we hope to demonstrate some of the consequences of cheap rate electricity causing simultaneous asset activity, which results in higher grid stresses than the baseline case.

Phase 3

In-home asset coordination

PassivSystems will develop algorithms which coordinate assets within the home to make best advantage of the variable availability of cheap electricity, the different storage potential of the assets, and the various patterns of consumption needed by the occupiers. These will calculate the best strategy for the householder in terms of minimising running costs against the variable tariffs.

The purpose of this phase will be to find out how the patterns of asset operation change when they move from uncoordinated to coordinated control within the home, and whether this makes the impact on the local grid bigger or smaller.

Phase 4

Local grid interventions

In this final phase we will identify some key grid problems (for example, times of peak load), and will design some interventions that demonstrate that an inter-home coordination system could mitigate some of the problems. This could, for example, involve pushing down to the control algorithms a whole-house maximum power constraint which is applied across the set of flexible assets, and might result in more pre-heating by the heat pump and a transition to gas heating at the time that the EV is plugged in and the sun has gone down.

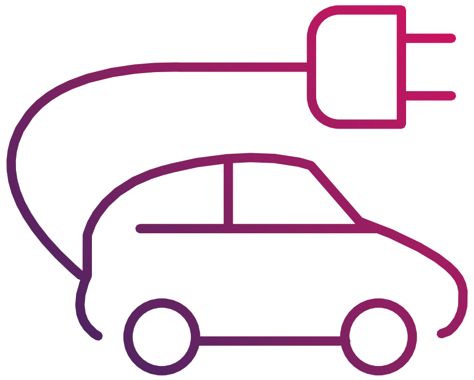
12.6

PASSIVSYSTEMS ANALYSIS AND COMMENTARY

In this final section, we provide some overall analysis to compare and contrast the five different approaches, bringing these together to suggest what it means for the rest of MADE and how the field trial should be shaped.

The Electric Nation dataset gave really valuable insight into current patterns of EV usage. We expected to see people plugging in their EVs in the early evening and leaving them to charge overnight, but there is also an interesting use case where EVs are plugged in for only a short period, presumably as a quick top-up before being used again. The overnight charges, where an early evening plug in coincides with high electricity demand, strongly support a case for demand management of EV charging, particularly for long connection durations (greater than nine hours). However, the Electric Nation analysis also demonstrates that care will need to be taken to ensure that the observed short top-up charges are not negatively affected by demand management when required by the EV user.

THE ELECTRIC NATION DATASET GAVE REALLY VALUABLE INSIGHT INTO **CURRENT PATTERNS OF EV USAGE.**



We also found that fully electric vehicles typically did not undergo a full charge in a single charging transaction, with a mean SOC increase of 41% during one transaction. Thus, EV charge duration is relatively short compared to the operating time of other energy assets within the home – but EV charging operates at a much higher power rating. This leads to a "short and sharp" demand spike, giving potential for peak load management either in aggregate or by limiting charging range of individual homes. This short demand spike also led to a dominant effect in the MADE modelling, as the cost of charging could be change quite significantly on a ToU tariff.

- The Domestic Techno-Economic Modelling by Everoze considers the flexibility value of adding a domestic battery and improved EV charging control, on top of a baseline system which is already operating a HHP to make the best use of a time-of-use tariff. As part of the trial, PassivSystems intends to explore:
  - **a** the benefits of the time-of-use tariff itself (contrasting Baseline operation on a flat tariff with National-scale grid drivers represented by a time-of-use tariff) and
  - **b** the additional benefits of HHP flexibility (as the heat pump can participate in the demand side response (DSR) mechanisms explored by Everoze and in particular coordinate its usage with the domestic battery).
- The Whole System Modelling by Imperial makes a strong case for the value of flexibility offered by HHPs and EVs, with V2G capability included in this analysis. It should be noted that this modelling does not include domestic batteries, although they will be included as part of the MADE trial.
- The Business Models work by Delta provides a comprehensive piece of analysis on the varied challenges of deploying expensive LCTs at scale with the requirements and concerns of householders addressed, as well as considering the crucial potential future value streams from DSR, etc. (both on the national and local scale).

The three final options for the customer proposition have different implications for the MADE field trial:

The **"All inclusive"** option where the customer does not have to pay for the assets and simply pays a monthly fee is a highly attractive option, although puts considerable investment risk on the provider of such a scheme (for example, seasonal variability could cause huge increases in outgoings if the monthly fee is truly fixed). The energy costs to the provider in this case are likely to closely reflect the electricity wholesale price, plus distribution charges – which matches well with the tariff underlying all of Everoze's modelling. While it will not be possible to test the overall business model in the MADE field trial, we certainly anticipate testing this ToU tariff.

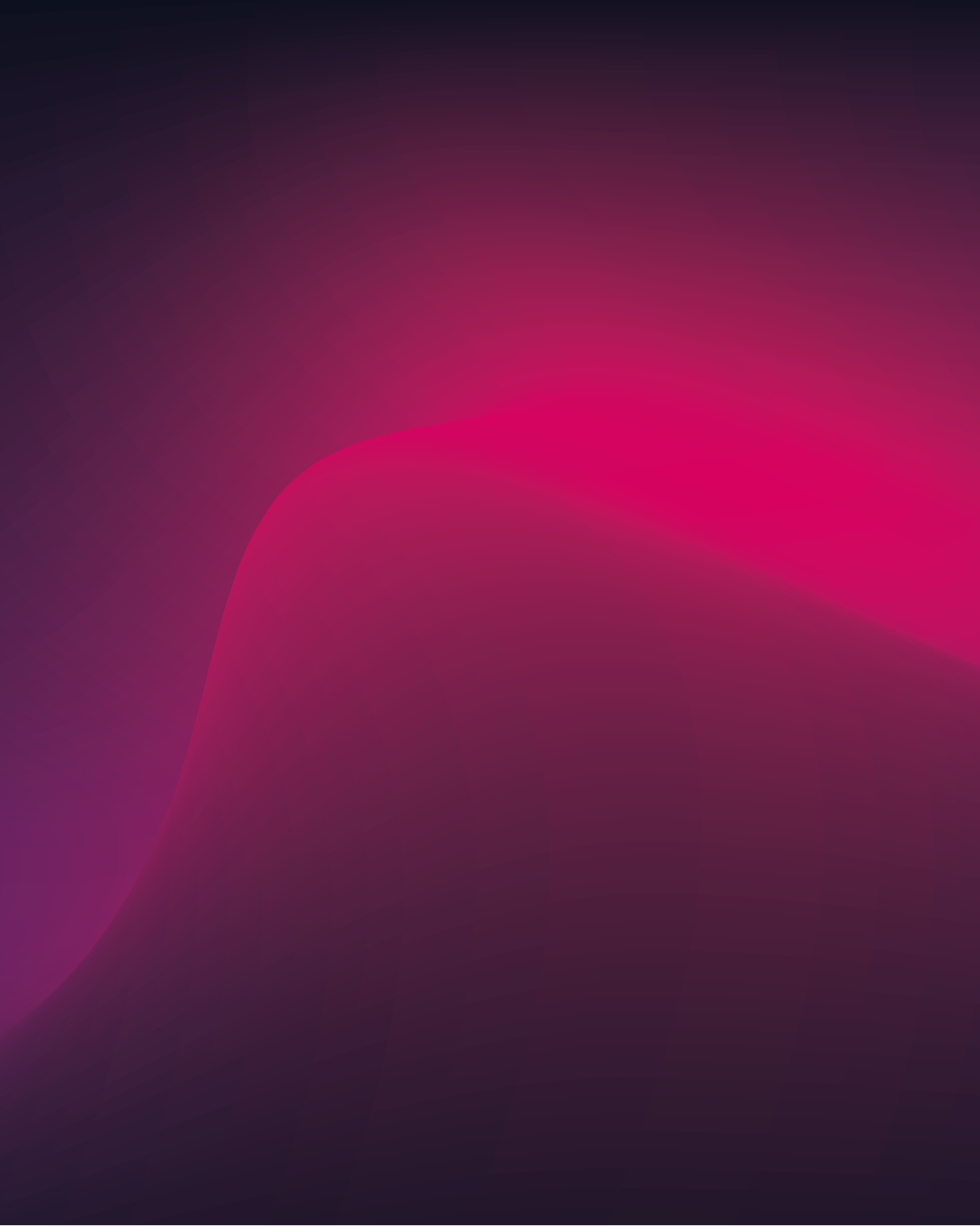
The **"Buying enhanced control"** option carries an obligation on the provider to constantly demonstrate the value of the system to the customer (as they are paying for the advanced services), for example, providing a tariff-switching service that delivers quantified savings, or direct feedback on the income they are receiving from DSR services.

The **"Minimising peak demands"** proposed an offering that excludes the PV and battery storage assets, which is a scenario that we plan to cover by the baseline phase of the field trial when the solar and battery assets will be largely ignored, and the heat pump and EV operate independently.

The customer engagement research by Delta-EE provided valuable insights into the attitudes of consumers towards the low-carbon assets forming part of the MADE system. Cost of heating is a major concern, so it is essential that future propositions deliver cost savings to the consumer – which will be challenging in the current economic environment where natural gas is very cheap. Consumers were positive towards having a domestic battery, but it is not clear how this squares with the high capital cost of meaningful battery capacity. There was some discrepancy regarding EV usage between the customer engagement research results and the Electric Nation dataset, in particular surrounding the length of time that the EV was typically connected to the charger. The survey results indicate that consumers most commonly leave their EV plugged in for one to two hours at a time, however the mean connection duration from the Electric Nation dataset was around thirteen hours; our inclination is to trust the quantitative measured data more than consumers' perceptions. There is quite a positive story about the willingness of EV owners to allow flexible charging, but a marked reluctance/conservatism among non-EV-owners, meaning there will be a significant challenge in addressing consumers' concerns in advance of large-scale recruitment.

THE CUSTOMER ENGAGEMENT RESEARCH BY DELTA-EE PROVIDED VALUABLE INSIGHTS INTO THE ATTITUDES OF CONSUMERS TOWARDS THE **LOW-CARBON ASSETS** FORMING PART OF THE MADE SYSTEM.

Finally, for both heat and EVs, there was a strong note of caution about the acceptability of third-party control. PassivSystems' view is that it is crucial how third-party control is portrayed – if consumers think their heating is going to be arbitrarily cut off, or their EV won't be able to charge at the whim of a third party (which may have been their expectation during the Delta-EE research), they are going to be reluctant to accept it. On the other hand, if they understand that the third-party intervention is designed to do things they won't even notice (switch heating fuel source, or shift EV charging earlier or later while they sleep), and won't cost them anything (or can even reduce their costs), we suspect that consumers will be happier with the interventions.



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